Forum for Electromagnetic Research Methods and Application Technologies (FERMAT)

A Courseware about Microwave Antenna Pattern

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Abstract: We developed a low-cost automated pattern measurement system for characterizing the 2.4 GHz ISM-band antenna by using three-antenna method. The adopted components for the developed system can be easily accessible so that this system is valuable for teaching purpose. In a noisy non-anechoic environment, the measureable antenna gain ranges from −27.3 to 17.7 dBi and can be improved by placing the whole system in an anechoic room. Nevertheless, the implemented system is suitable for demonstration in a course related to wireless communication, antenna theory, remote sensing, radar and so on.

Keywords: Radiation pattern, low-cost antenna measurement system, automation, three-antenna method.

REFERENCES

[1] John D. Kraus and Ronald J. Marhefka, Antennas For All Applications, Artech House, 2001.

[2] S.-C. Lin, "New microstrip cascaded-quadruplet bandpass filter based on connected couplings and short-ended parallel-coupled line," IEEE Microw. Wireless Comp. Lett., vol. 24, no. 1, pp. 2-4, Jan. 2014.

[3] Y.-S. Wang, M.-C. Lee, and S.-J. Chung , "Two PIFA-related miniaturized dual-band antennas," *IEEE Trans. Antennas Propag., vol.* 51, no. 3, pp. 805–811, Mar. 2007.

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Outline

- Introduction
- Antenna Characteristic
- Antenna Measurement Theory
- Hardware Configuration : Transmitter Side
- Hardware Configuration : Receiver Side
- Measurement Example
- Conclusion

Introduction(1/2)

- In the usual university course, it is not likely to afford the relatively expensive price to purchase and build a complete antenna measurement chamber equipped with a network analyzer just for teaching demonstration due to space and budget limitation.

- How to build a usable system with low cost but still acceptable performance is really an attractive topic.

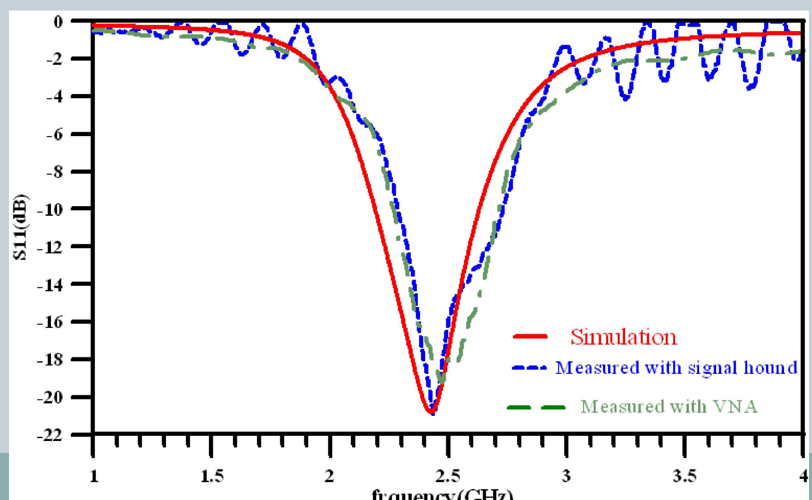
Introduction(2/2)

- For RF/microwave education, both "Seeing is believing" and "Learning by doing" are important learning strategies for students.
- An antenna measurement system capable of performing radiation pattern characterization is designed and implemented.
- The **three-antenna method** is adopted to obtain the absolute gain of the antenna under test.

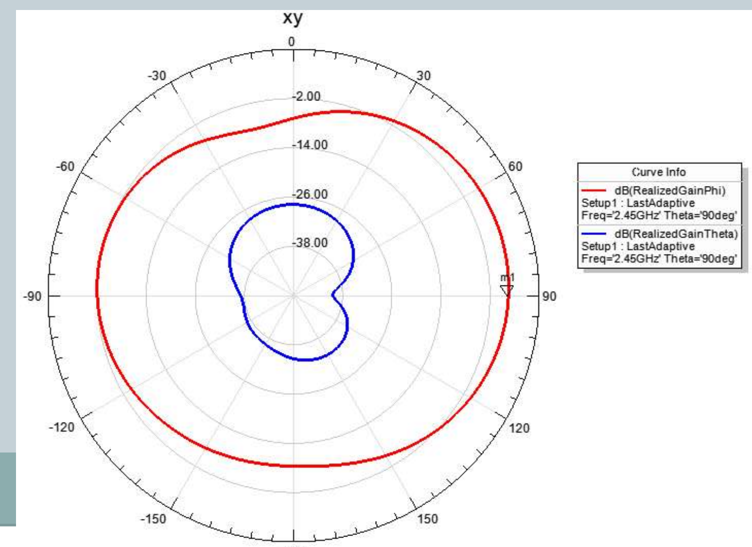
Antenna Characteristic (1/2)

- After an antenna is designed and implemented, the return loss has to be first measured to know if the operation frequency of antenna under test (AUT) fits the target.
- Second, the realized gain has to be then measured.

Reflection Coefficient



Realized Gain Pattern



Antenna Characteristic (2/2)

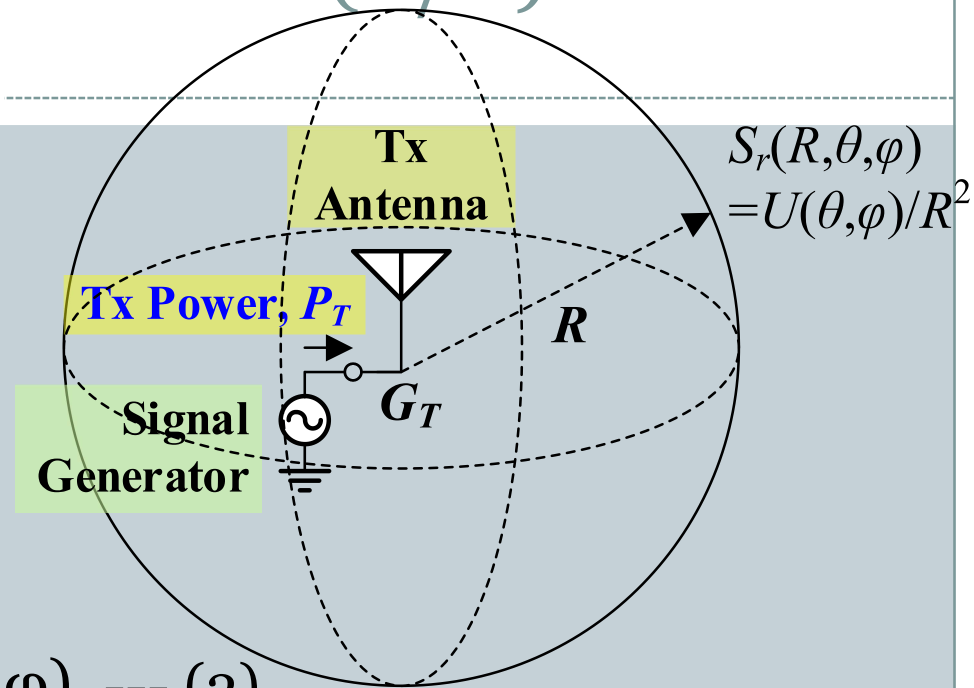
- The realized gain is defined :

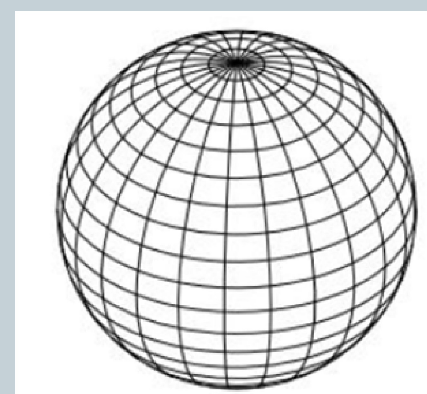
➔ $G_R(\theta,\varphi) = \dfrac{U(\theta,\varphi)}{Pav/4\pi}$ --- (1)

- Based on the Friis equation :

➔ $P_R - P_T = G_T + 20\log(\dfrac{\lambda}{4\pi R}) + G_R(\theta,\varphi)$ --- (2)

- If the gain of transmitter antenna is fixed, the normalized gain pattern can be obtained by (2) using two-antenna method.





PR : receiving power
PT : transmitting power
GT : Tx antenna gain
GR : RX antenna gain
20log(lambda/4*pi*R) : path loss

Antenna Measurement Theory (1/3)

- A typical antenna measurement approach shown in Fig. 1, so-called three-antenna method (TAM), is based on three antennas including antenna under test (AUT), reference antenna (REF) with unknown gain, and an antenna with well-known gain (STD).

- Using two antennas REF and AUT
  - The power received P_{R1} and P_{R2} can be used to obtain the absolute gain of AUT.

$$\Delta P = P_{R2} - P_{R1} \quad \text{--- (3a)}$$
$$G_{AUT} = G_{REF} + \Delta P \quad \text{--- (3b)}$$

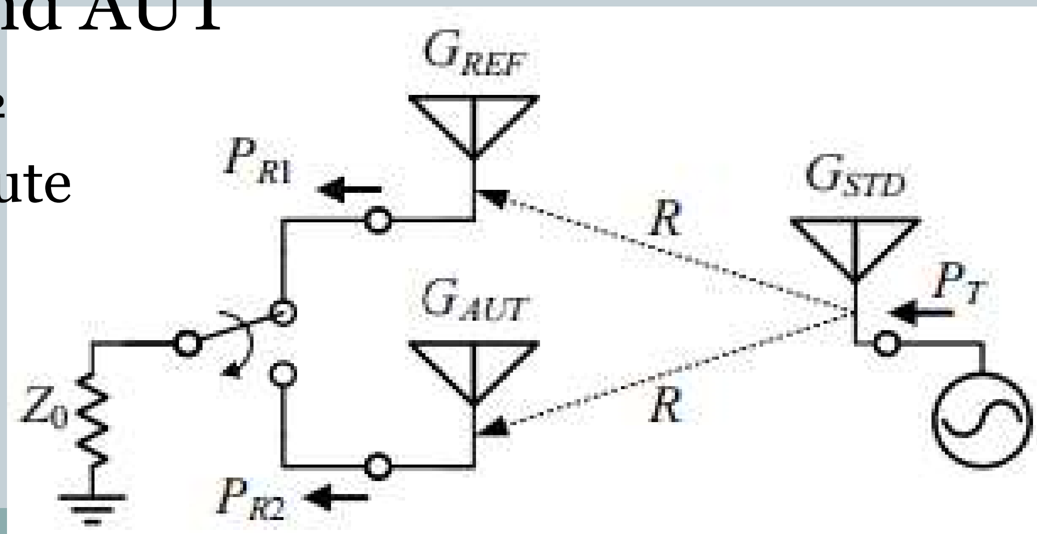
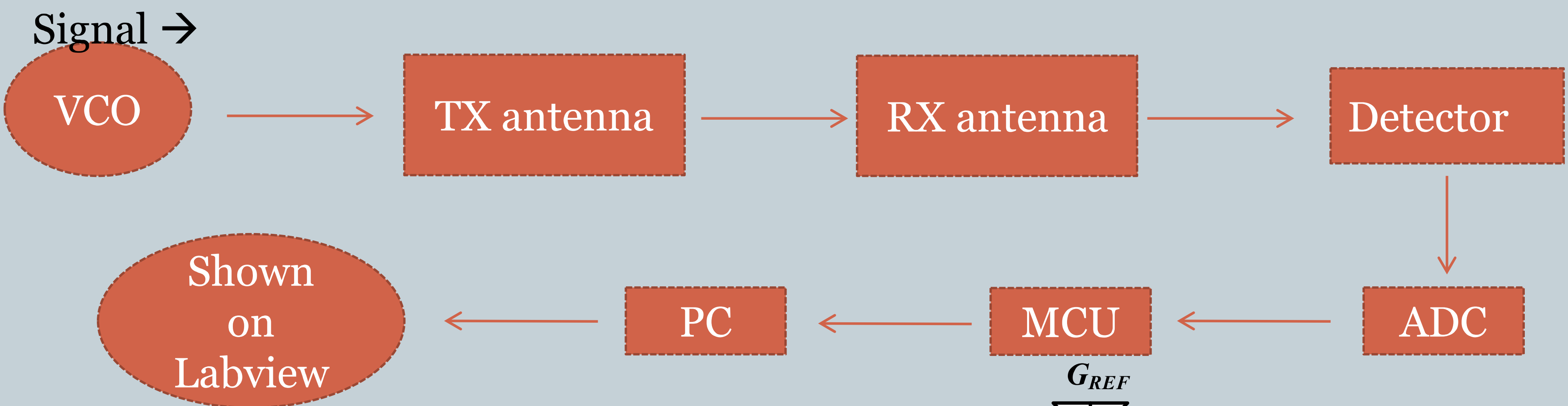


Figure.1 Three-antenna measurement method

Antenna Measurement Theory (2/3)

- We target on implementing a system measuring the antenna at 2.45 GHz.



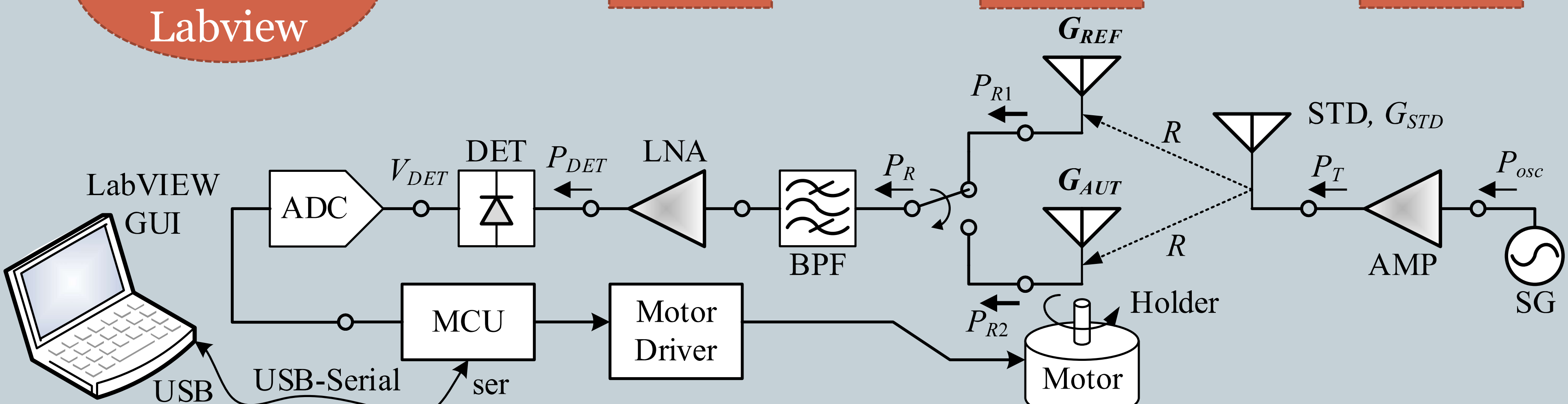


Figure .2 **Hardware configuration of the implemented low-cost portable automated antenna measurement system**

Antenna Measurement Theory (3/3)

- The perspective view of the implemented complete system associated with the block diagram in Fig. 2 can be seen in Fig. 3.

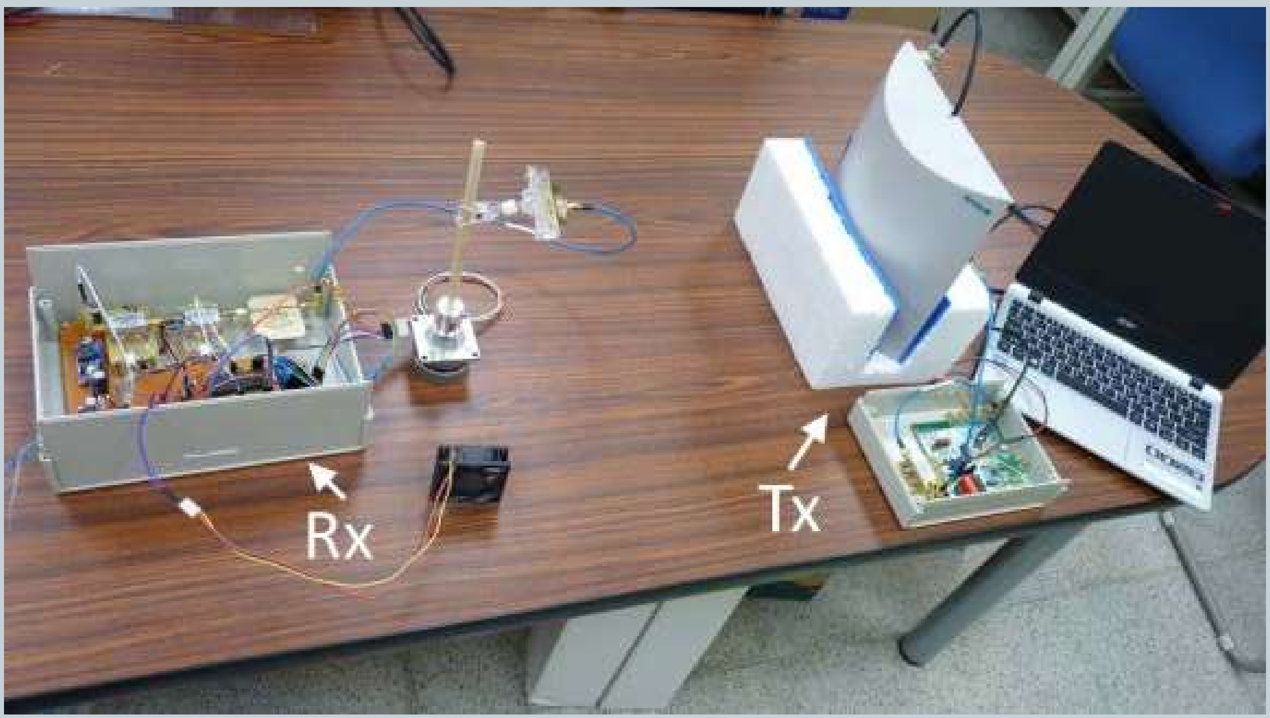
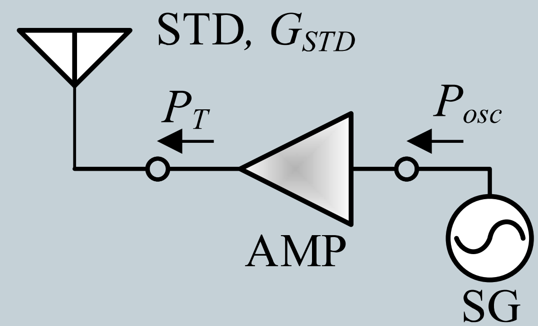


Figure.3 Perspective view of the automated antenna measurement system.

Hardware Configuration : Transmitter Side (1/3)

- The transmitter hardware consists of a signal generator, an amplifier and a standard antenna as displayed in Fig. 4.



- Hardware :
  - Signal Generator (SG)
    - A powerful chip ADF4350 wideband frequency synthesizer with built-in VCO.
    - The output frequency ranges from 137.5 MHz to 4400 MHz while the output power can be practically -2.3, 0.4, 3.3, and 6.3 dBm.

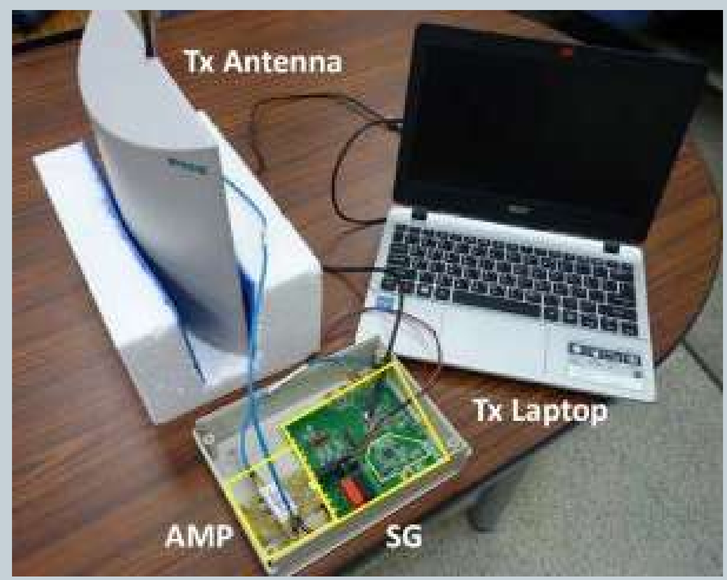
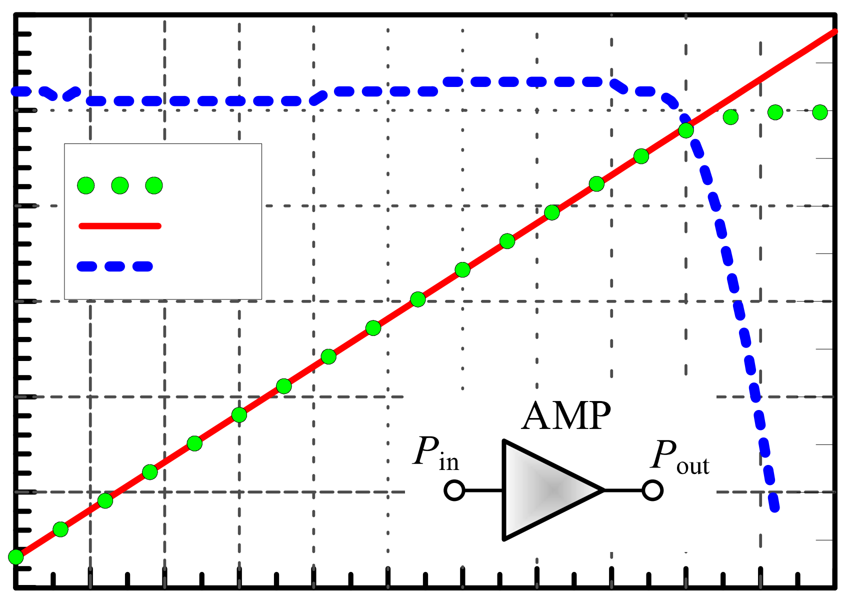


Figure .4 Perspective view of the transmitter side in Fig. 3

Hardware Configuration : Transmitter Side (2/3)

- Hardware :
  - Amplifier (AMP): Gain of 13.2 dB
    - To amplify the signal transferred from VCO, the MiniCircuits ZX60-272LN+ low-noise amplifier [4] is chosen for providing sufficient high output power.



ure .5 Measured output power vs. input power characteristic at 2.45 GHz.

Hardware Configuration : Transmitter Side (3/3)

- Hardware :
  - Tx Antenna (STD)
    - To avoid the environment multiple reflections and efficiently transmit the RF power, Tx antenna must possess the beamwidth narrow enough and the antenna gain high enough.
    - A commercial high gain directional panel antenna with 14 dBi gain and 30° HPBW (half power bandwidth) is picked up.

Hardware Configuration : Receiver Side (1/7)

- To capture the transmitted signal, a receiver is placed at far enough distance R = 3.7 m meeting the far-field criterion.

- The corresponding path loss is 51.6 dB according to the Friis equation.

$20\log(\frac{\lambda}{4\pi R})$

Hardware Configuration : Receiver Side (2/7)

- The receiver shown in Figs. 2 and 6 has more building components than the transmitter.

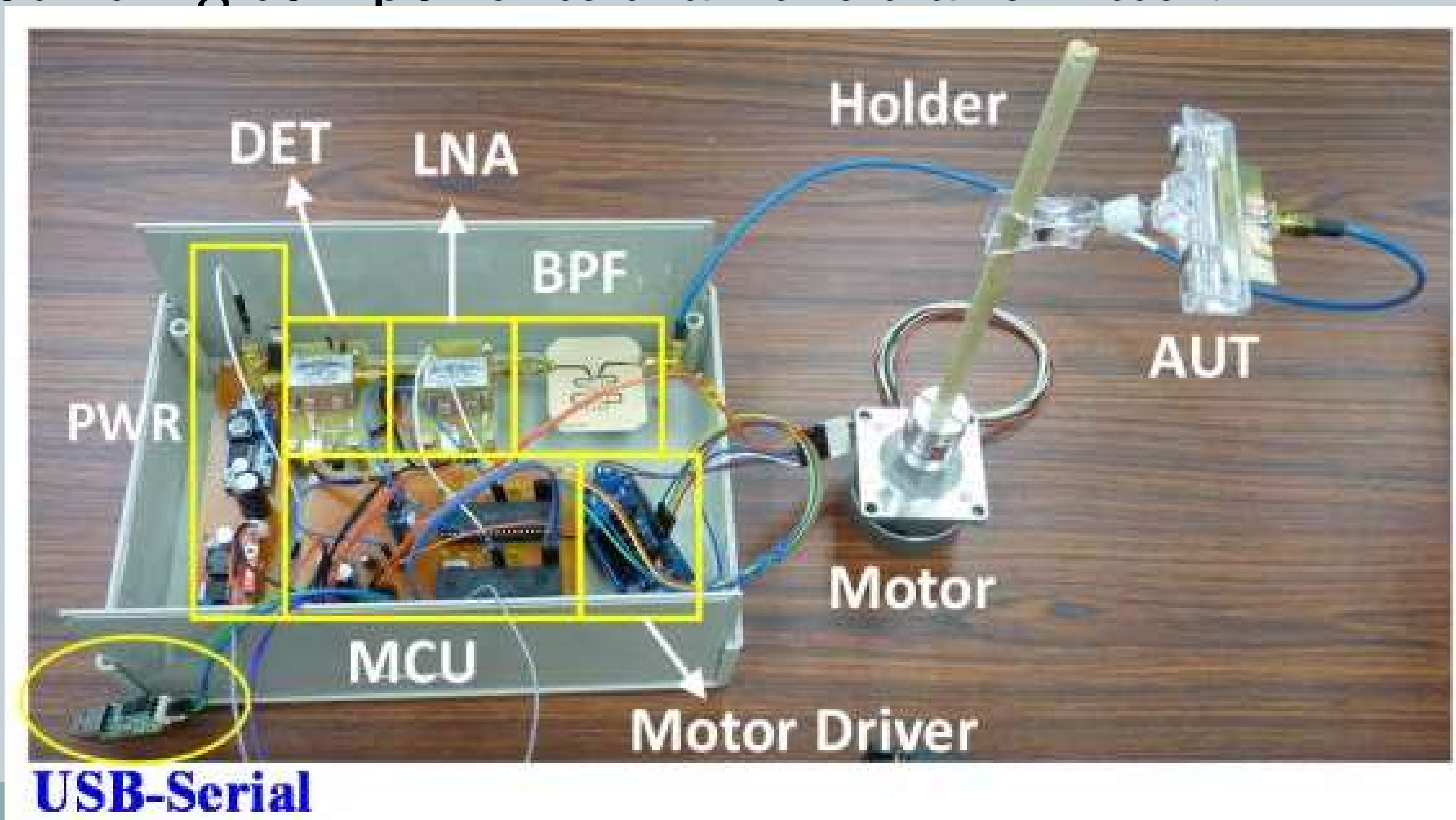


Fig. 6. Perspective view of the receiver side in Fig. 3.

Hardware Configuration : Receiver Side (3/7)

- Those building components are described as follows.
- According to the three-antenna method detailed in Antenna Measurement Theory , a reference antenna (REF) with known gain is required.
- A commercial 2x2 patch array antenna is adopted for reference. The gain of 14 dBi is also pretty high.
- Most important all, we need to prepare the antenna under test (AUT) for characterization

Hardware Configuration : Receiver Side (4/7)

- A 4th-order cascaded-quadruplet bandpass filter using quarter-wave resonators based on connected couplings and short-ended parallel-coupled line shown in Fig. 7.

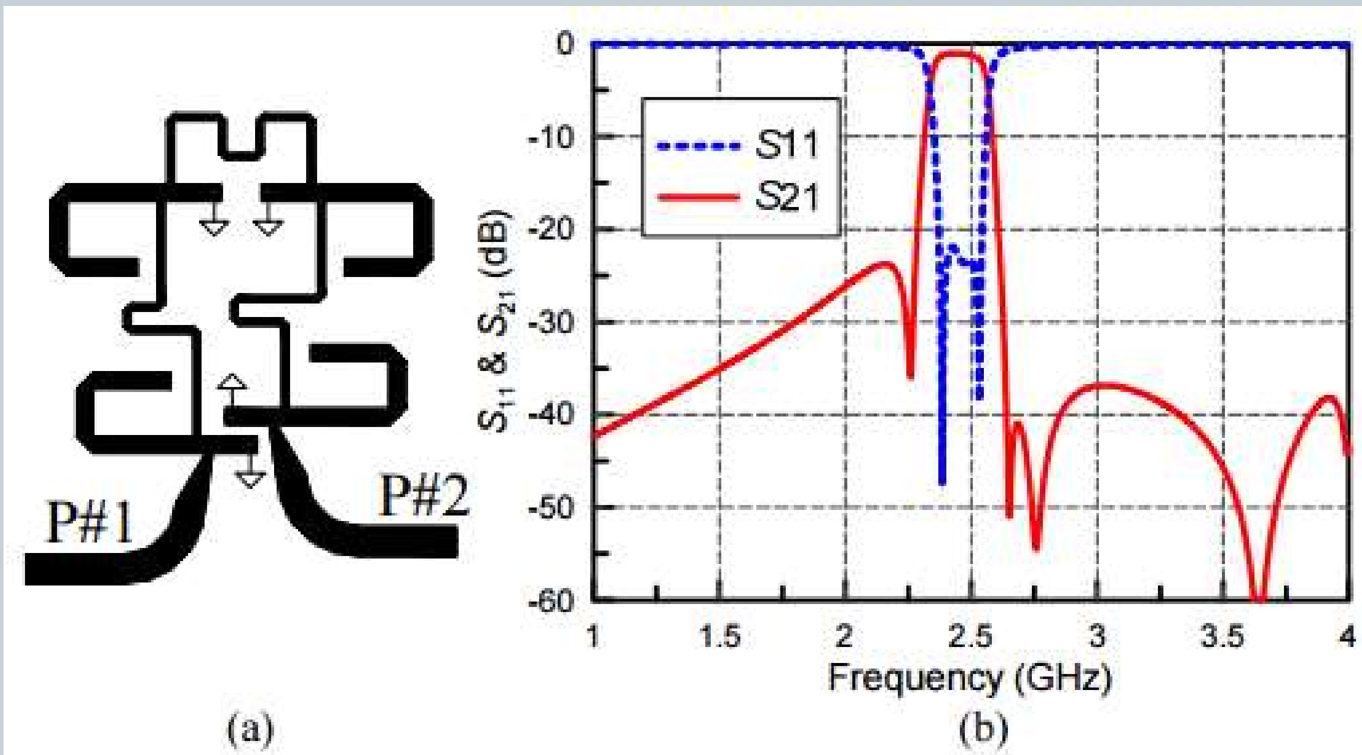


Fig. 7. Bandpass filter BPF in the receiver side. (a) Filter layout.
(b) Simulated transmission and reflection coefficients.

Hardware Configuration : Receiver Side (5/7)

- The filter is designed to filter out those out-of-band signal except the 2.4 GHz ISM band as illustrated in Fig. 8 to ensure the sensitivity of power detector.

- It centers at 2.45 GHz has 10% fractional bandwidth and relatively low insertion loss around 1.8 dB.

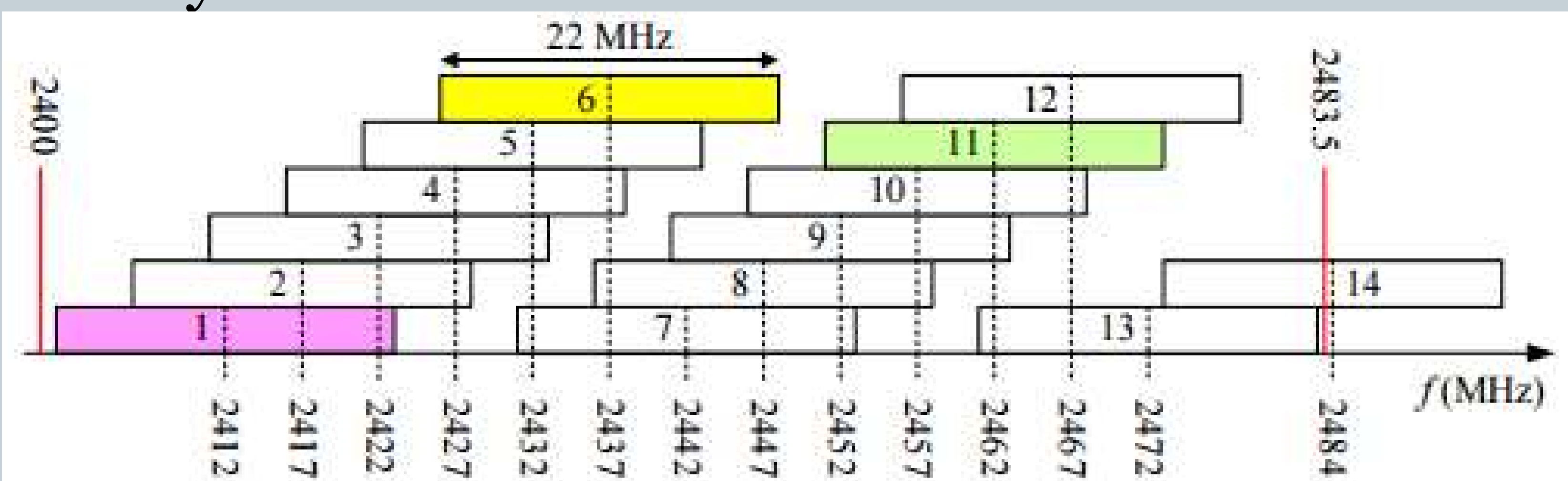


Fig. 8. Frequency map of the 2.4 GHz ISM band used by 802.11 b/g equipment.

Hardware Configuration : Receiver Side (6/7)

- Then, the signal captured either by REF or by AUT antennas will first be amplified by an exactly identical LNA ZX60-272LN+ in the transmitter side.

- Table I concludes the gain specification of each component described so far.

Table I
Gain Specification of Each Component

REF RUN

	STD	AMP	Path	REF	LNA	BPF
Gain	14 dBi	13.2 dB	-51.6 dB	14 dBi	13.2 dB	-1.8 dB

AUT RUN

	STD	AMP	Path	AUT	LNA	BPF
Gain	14 dBi	13.2 dB	-51.6 dB	???? dBi	13.2 dB	-1.8 dB

Hardware Configuration : Receiver Side (7/8)

- A Mini-Circuits detector (DET) ZX47-60LN+ with -60 to +5 dBm dynamic range senses the RF power and convert it to a DC voltage inversely proportional to input power.

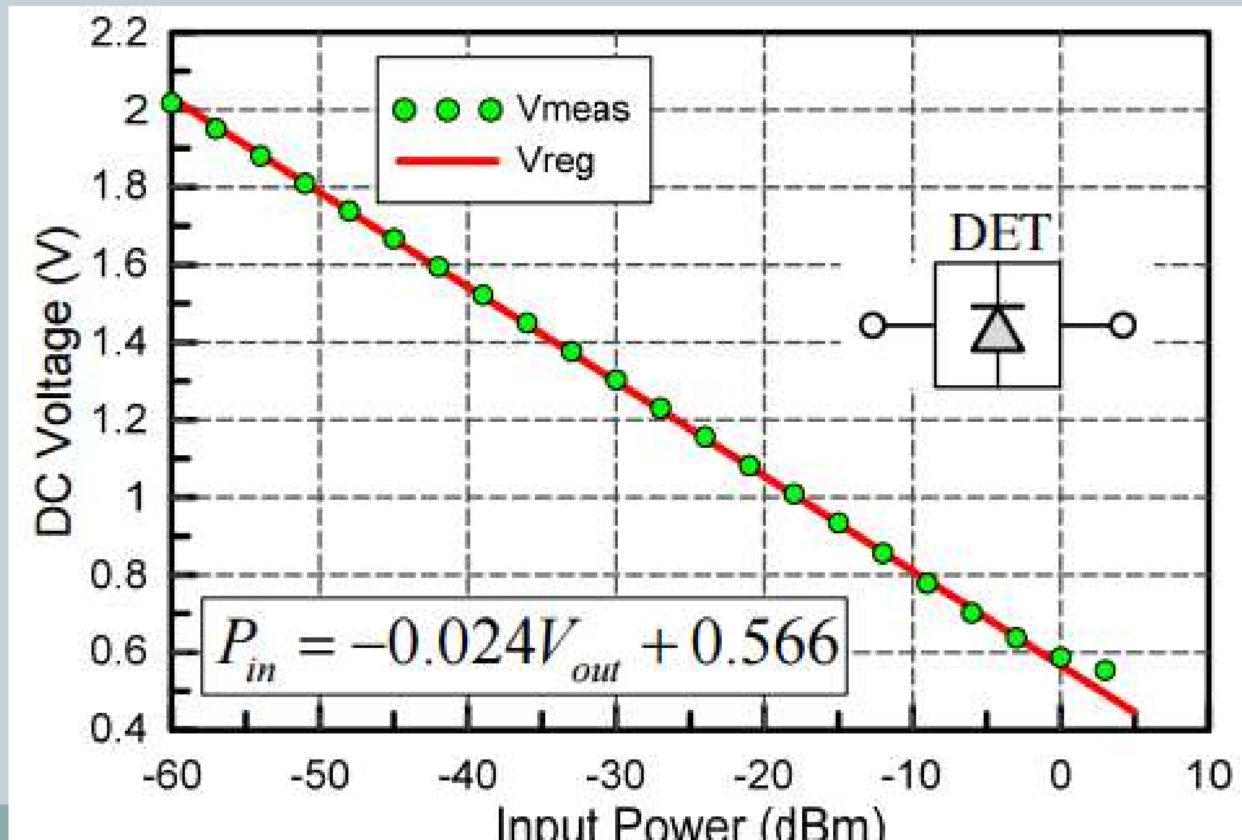


Fig. 9. Measured Vout vs. detector Pin characteristic at 2.45GHz.

Hardware Configuration : Tx + Rx

- P_T = -2.3 dBm, P_R ~ -3.7 dBm (ideal = -1.4 dBm) with all the losses from cables and connectors included using STD antenna
- If we estimate –60 to 0 dBm at detector input as the system dynamic range, the AUT antenna gain measurable should be from **–42.3 to 17.7 dBi**.
- The analog DC output voltage from detector will be digitalized and then a microcontroller 8051 is used to evaluate the digital value converted from ADC.
- Eventually, the transmitter and receiver are assembled and fitted into separate plastic boxes.

Measurement Example (1/3)

- Nowadays, in the common classroom, WiFi signals inevitably surround us thus limit the lower bound of received power.
- Use spectrum analyzer to measure the output of BPF, we can observe the noise and interference power spectrum around us
- This strong interference reduces the gain sensitivity.

The lower bound of gain degrades to -27.3 dBi.

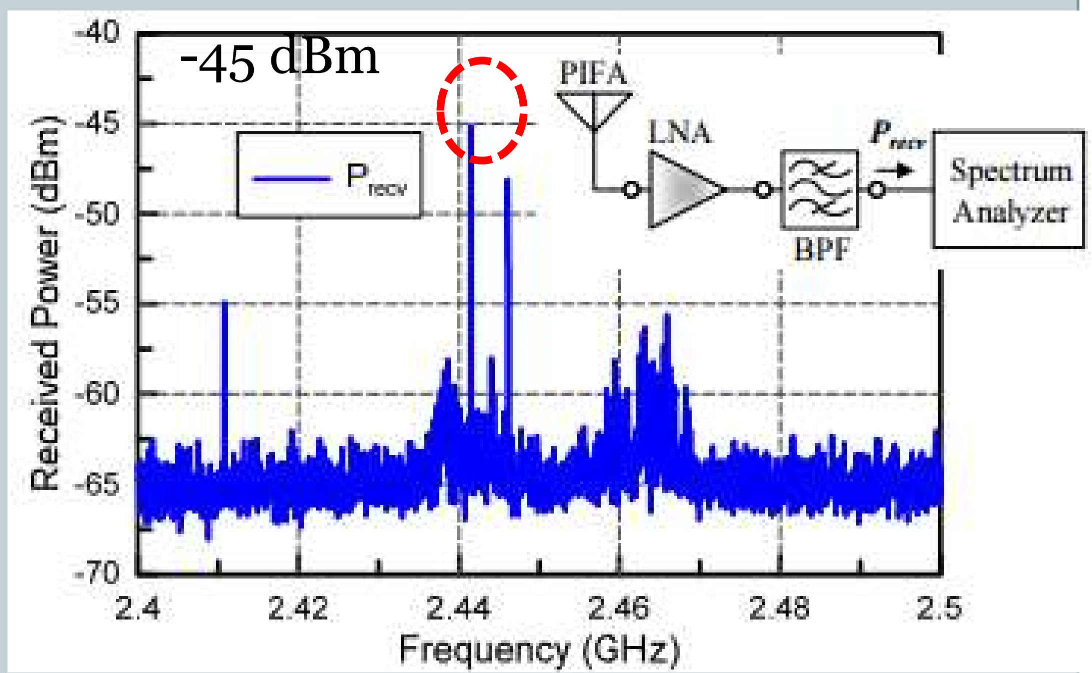
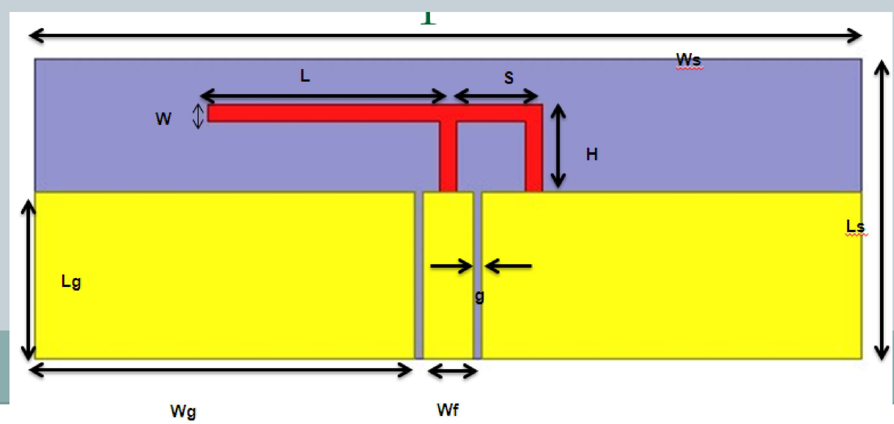


Figure . 10 Measured environment noise and interference power spectrum and its measurement setup

Measurement Example (2/3)

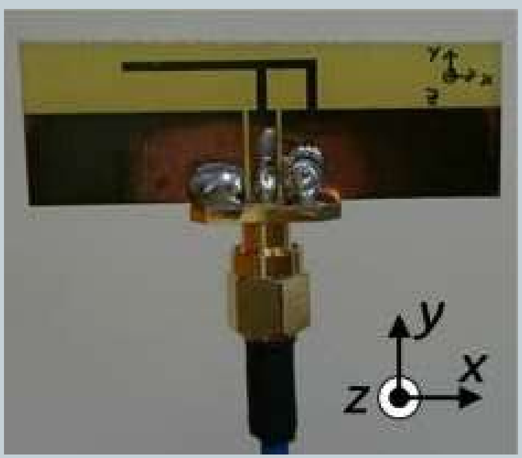
- To demonstrate the capability of the antenna measurement system, a planar inverted-F antenna is designed and fabricated on the 1mm-thick FR4 substrate (εr = 4.4, tanδ = 0.02).
- The simulated peak gain on the x-y plane is 2.78 dBi. (the measured peak gain of the PIFA is found to be 3 dBi very close to the simulation.)
- The photograph of the fabricated antenna is shown in Fig. 11.



Measurement Example (3/3)

- Results
  - The measured and simulated *xy*-plane radiation patterns of the gain φ component for the AUT is illustrated in Fig. 12.
  - The measured results coincide pretty well with the simulated ones even in a noisy non-anechoic environment.

Measure the xy-plane gain pattern using the implemented system



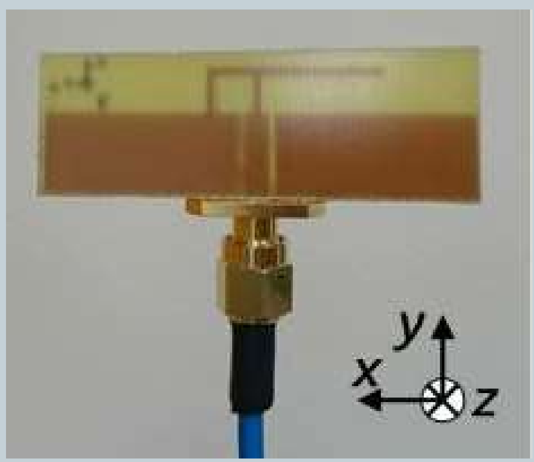


Figure .11 Photograph of the fabricated planar inverted-F antenna.

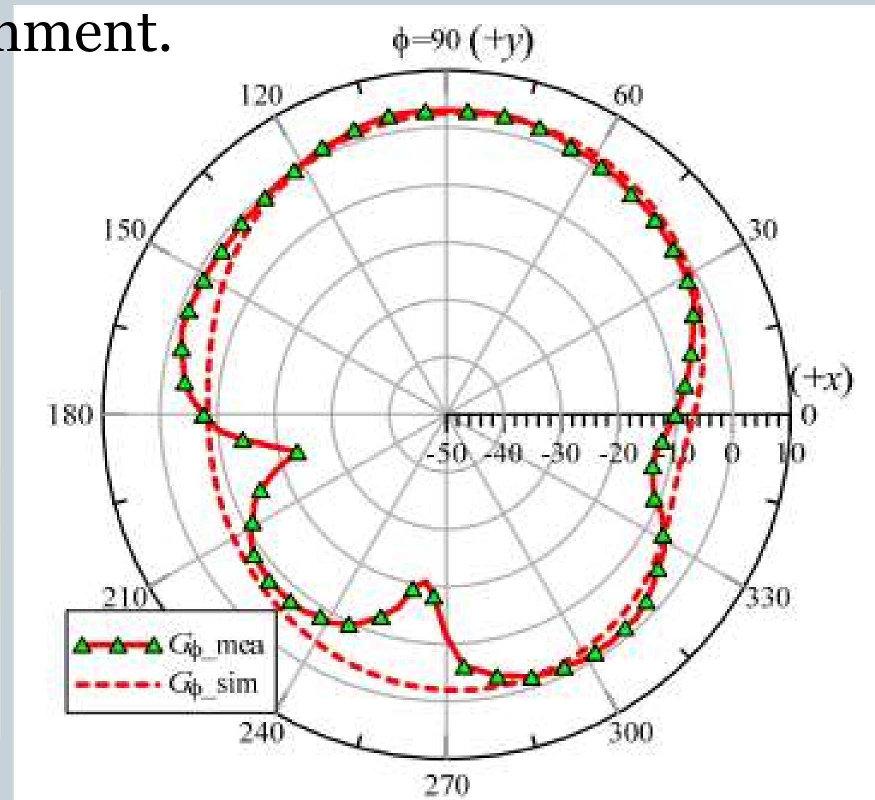


Figure . 12 xy-plane radiation patterns of the gain φ component for the AUT

Conclusion

- A low-cost automated pattern measurement system for characterizing the 2.4 GHz ISM-band antenna has been demonstrated.
- In a noisy non-anechoic environment, the measureable antenna gain ranges from −27.3 to 17.7 dBi and can be improved by putting the system in an anechoic room.
- The implemented system is suitable for demonstration in a course related to wireless communication, antenna theory, remote sensing, radar and so on.

Thanks for your listening